IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)	
Title	**Adaptive Frequency Hopping ad-hoc group update**	
Date Submitted	10 May, 2001	
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Re:	Update on AFH submission to TG#2	
Abstract	This document describes the deliberation process of the Adaptive Frequency hopping proposal. It contains details as to what issues are pertinent to an adaptive frequency hopping mechanism and how it may be implemented in a Bluetooth/802.15.1 communications system.	
Purpose	This document will give 802.15 TG2 a broad overview of the progress of the TG2 Adaptive frequency hopping ad-hoc group.	
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Introduction

This document will give an outline of the proceedings of the teleconference calls that too place between the IEEE plenary meeting in Hilton head and the IEEE Interim meeting in Orlando. There were five teleconference meetings in which were overseen by Nada Golmie and regular attendees included participants from Bandspeed Australia, TI Dallas, TI Israel, IPC Taiwan.
The purpose of the ad-hoc group was to come to some final agreement on a formulation for an Adaptive frequency hopping proposal.
The rest of this document outlines the discussion points and which points were agreed upon and which points are still to be discussed.

Summary of solutions

- Bad channel replacement under legacy hopping sequence
- Pairing/group of bad channels
- Reduction of hopping sequence length

Summary of discussions

The AFH proposal has be sectioned off into three major sections. The sections are described below:

Channel Assessment / Channel Categorization

Classification relates to the problem of identifying the channels with 'bad' characteristics. Various points were discussed including:

- The speed at which classification should take place;
- The expected types of devices that would be required to be avoided;
- The bandwidth of the interferers that would be required to be avoided;
- Re-assessment of the channels must take place at regular intervals;

Some ideas as to an expected time that the classification should take place were tabled. General feeling that the time that classification should take is generally application dependant. Voice applications can only deal with a small interval of degraded throughput, thus a faster classification system is needed. ACL Data links, however, are not usually time critical, and thus the requirements are somewhat relaxed.

Mechanism of Adaptively Hopping

The technique is probably the most contentious issue and one that requires thorough investigation. Various points which were discussed included:

- The issue of backwards compatibility
- The impact of FCC regulations on the possible choices of algorithms
- Maintain synchronization for all devices on the network

Broadcast packets were discussed quite extensively, Broadcast packets require all devices to receive on the same channel, this creates problems for most AFH systems. "Replacement of bad channels under legacy hopping sequence" algorithm is the only algorithm which addressed broadcast packets, parking and un-parking procedure.

FCC regulations were also discussed. Grouping/pairing is currently legal (with some clarifications from FCC) under FCC regulations. The replacement algorithm requires a modification to the FCC regulations and currently is only legal for low power devices.

The restrictive-ness of the grouping/pairing system was also suggested. Grouping/pairing does not work with HV1 packets, works with a maximum of 1 HV2 packet connections and 2 HV3 packet connections. Pairing on SCO links will compromise ACL traffic, and grouping on ACL traffic will compromise SCO traffic. It was suggested that grouping can conform with different scenarios.

Reliable exchange of channel catagorisation

(Yet to be discussed)

Some discussion points include:

- Must be a robust mechanism that ensures a 'safe' transition b/w hopping sequences.
- Bulk channel replacement, channel at a time optional

Points of consensus

- AFH system comprises of channel classification, updating devices with new sequence and an AFH mechanism of “Replacement of bad channels under legacy hopping sequence” / ”pairing/group of bad channels” or “reduction of length of sequence”.
- Channel classification speed is application dependant
- AFH Mechanism must be backward compatible
- Both the ”pairing/group of bad channels” and “Replacement of bad channels under legacy hopping sequence” algorithms can be used in different scenarios.
- Proceed with an AFH proposal regardless of FCC laws
- Throughput should be improved for all links without compromise
- Complexity of systems should be minimized
- Synchronization of all devices should be maintained.
- Minimize changes/additions to existing standard

Points of contention

- Device update using ‘channels at a time’ or ‘many channels at once’
- Whether links b/w Master and all slaves should use different AFH sequences
- Broadcast packets are important and relevant to a Bluetooth system
- All types of interferers should be taken into account in the classification process
- Methods of parking and un-parking slaves must be supported.

Points of further discussion

- During which states should AFH be implemented?
- When should classification be done? Before and/or during?
- Management of Master to Slave switches and/or scatternet

Previous telecon minutes

Teleconference #1

Summary of first IEEE802.15.2 AFH Teleconference (March 28, 2001)

Oren Eliezer, Texas Instruments Israel (Short Distance Wireless) - March 30, 2001

Attended:

TI Dallas (Anuj), NIST (Nada), TI Israel (Oren), IPC Taiwan (H.K. and K.C.), and Bandspeed Australia (Bijan, Hongbing and others). Nada arranged for the bridge and lead the discussion.

Points/Goals for Discussion

Bandspeed's points agreed upon as start point. The first one, "Channel Assessment/Categorization", was to be the primary focus of this first telecon.

Legal Issues with Bluetooth SIG

I brought up the importance of the Bluetooth SIG accepting and implementing whatever ideas we come up with regarding frequency hopping, and expressed concern that this might not happen in light of legal issues brought up in the SIG's teleconference I had attended the day before. The claim made by some SIG members was that only SIG member companies are singed on agreements according to which the SIG can make use of their IP, so that as the Bluetooth standard or revisions of it are developed, there is no licensing concern that is related with ideas coming from them. As an example, Steve's proposal for improving speech links ("SCORT"), presented at Hilton-Head and also submitted to the SIG, was discussed. The consensus was that since Symbol is a SIG member, if the SIG were to adopt principles from "SCORT", there weren't be a legal issues.

KC from IPC suggested that we continue with our work regardless of such potential issues, and we all agreed that our primary goal is to come up with a mechanism we believe would be optimal in terms of coexistence performance. Acceptability or "marketability" of it can be examined later.

I recommended that Steve, as our TG chairman, also make use of his contacts in the SIG and look into possibilities of resolving such legal issues. In the SIG telecon it was mentioned that the IEEE does not own any of the IP in the documents its produces, but there might still be some other solution that the IEEE can come with to resolve the legal issues with the SIG.

IPC mentioned having some contact with Ericsson, which I believe would be helpful, since if they were to have an agreement with Ericsson regarding IP licensing, then IP coming from IPC may be regarded by the SIG as coming from Ericsson, thus solving the legal issues for IP coming from IPC.

Channel Assessment Discussion

Points brought up / agreed upon:

- I made the claim that the amount of time it takes to achieve reliable channel assessment should be compared against an absolute figure. In other words, rather than comparing two schemes, and arbitrarily preferring the one that accomplishes this in less time, the channel assessment mechanism should comply with some requirement that is derived from actual application needs.
- We all felt that voice is a typical and common application for which the requirements are likely to be most stringent (in terms of allowed packet losses and time for hopping sequence adaptation).
- I had proposed an arbitrary transition time in the order of 1 second, but most felt that a magnitude in order faster (the order of 0.1sec) would be more appropriate for voice, in order for it not to be noticed by the user.
- After an attempt to estimate the number of hops and failures per channel that would be experienced during a given period of time, KC from IPC said he would perform statistical confidence calculations off-line, assuming a practical transition time, hopefully showing that reliable adaptation decisions can be made in short intervals of time.
- A packet error rate of 5% was claimed to be unacceptable in uncompressed voice packets, so the threshold decided upon was 1-2%. This might change if proof is provided according to which voice quality could be acceptable for higher PER, or alternatively a better PER is required. Any input on this would be greatly appreciated. The assumption is that we need to provide "toll quality" voice.
- How can packet failure be detected? CRC on voice payload does not exist in Bluetooth, but maybe this can be added. FEC error indication could be used, when FEC is present. FEC is not effective in protecting packets against interference, so we are not promoting it for this purpose. CRC is lest "wasteful" in BW/throughput and does the job of providing such indication.
- I claimed that the combination of RSSI and CRC seems to be desirable since we might want to distinguish between an interfered frequency and a case of weak connection (or multipath fading). The latter would be characterized by low RSSI and possible bad CRC, while in the former, a bad CRC indication could be accompanied by a surprisingly high RSSI reading (corresponding to the level of interference rather than desired signal).
- Backwards compatibility - we realize that an improvement idea could be accepted by the SIG, if through its implementation, backwards compatibility could still be maintained. We concluded that we could always maintain this if we are to allow the connection to remain as in Bluetooth 1.1 (without improvement) and offer the link improvement only in those cases where an improved Bluetooth device is present at both ends.
- KC proposed detecting wideband interference (such as an 802.11b signal). Concerns were raised regarding the realization of this in terms of hardware (the implementation of a wider RF filter in a narrowband system typically having a 1MHz filter such as Bluetooth). The ability to detect the presence of a wider signal, such as 802.11b, and immediately avoid its entire sub-band, without having to scan it in separate 1MHz steps, is obviously advantageous.

- We were trying to estimate the number of coexisting BT units for which collision will start to be problematic for a voice link. It seemed to us that two piconets would not create enough interference for each other to be noticeable in terms of voice quality degradation (probability for collision is below 2%). We estimated that only once 3 or more piconets are coexisting, this could be noticeable. This assumed that no other interferers are present, and that the Bluetooth piconets use all 79 channels, as in the current specifications.
- Anuj claimed that 100 coexisting piconets are to be considered (Anuj, did you really, or am I not reading my notes correctly?…)
- Bandspeed: 3-4 piconets are a reasonable assumption. An estimate of 0.4 probability for packet loss was given for 100% duty cycle in the coexisting piconets. That would be unacceptable.
- Bandspeed: probability of collision increases as number of hopping channels is reduced.
- I claimed that the assessment of situation is faster when less hopping channels are used (I elaborated on this enough, including the sequence cycle issue, in Monterey and in Hilton-Head…).
- Anuj: an example of many coexisting piconets: telemarketing, where all telemarketers are using BT based headsets. I didn't think that was reasonable, since they are typically stationary and don't need to roam around an office, so they could simply use wired headsets. In addition, they would be typically sitting in a line, and not circle, so the further away telemarketers could be using the same frequency at the same time without interfering with each other (sufficient C/I values).
- Anuj told us about his coexistence experiments with Bluetooth and cordless phones at 2.4GHz that are in the market. The two different phones (Toshiba and GE) behaved differently (do not employ the same modulation/spreading scheme). We need to consider this type of user of the band as well! Consumers will not be happy to bring home 2.4GHz gadgets that would interfere with their already existing 2.4GHz phones (which are becoming very popular, at least in the USA).
- Bandspeed proposed a generalized approach to be able to operate in the presence of all sorts of signals that could be in the band in the future, possibly unforeseen today. As much as this makes sense, I claimed that we need to focus mainly on those signals that we know are out there already (e.g. 802.11b and Bluetooth) and proposed using weights that would reflect the prevalence of each. This is to enable us to prefer one mechanism to another if it performs better with the more prevalent coexistence scenarios, possibly even if it does worse in some rare coexistence scenario.
- I took the action item to build a table of 2.4GHz sources/systems (2.4GHz lighting elements and microwave ovens are just "sources"). This table will be based on market data that will enable us to estimate the probability of a particular signal being encountered in a home or office environment. In addition, the table will provide some basic parameters for each of the signals/systems (interference susceptibility, BW of signal, duty cycle, power, etc.). I will send out a first revision within about two weeks, and you are all welcome to fill in the may empty cells that will be in there, as well as comment on those for which I will enter initial values myself.

Oren Eliezer
Texas Instruments

Teleconference #2

Summary of second IEEE802.15.2 AFH Teleconference (April 5, 2001)

Oren Eliezer, Texas Instruments Israel (Short Distance Wireless) - April 11, 2001

Attended:

TI Dallas (Anuj), NIST (Nada), TI Israel (Oren), IPC Taiwan (K.C.), and Bandspeed Australia (Bijan, Hongbing, Vitally). Nada arranged for the bridge and lead the discussion.

Points/Goals for Discussion

Detection and transition time, and categorization of interference sources were to be the primary focus of this second telecon.

Legal Issues with Bluetooth SIG

Companies might have to sign agreements with the SIG in order for their ideas to be accepted and incorporated into the Bluetooth standard.

Transition Time Discussion

Points brought up / agreed upon:

- Larger bandwidth of detection, when feasible, allows faster channel assessment (detect whole portions of band being occupied rather than each hopping channel at a time).
- Transition time may be application dependent (some applications might require faster adaptation).
- It was proposed to allow vendors to set transition times. However, the algorithm/mechanism must be designed such that it would be able to meet the anticipated needs of the various applications (in particular the more sensitive ones, such as voice).
- Differences in "error sensitivities" of various applications were discussed, with specific issues brought up: packet loss (tolerable for ftp), errors in payload (for voice vs. data), voice cannot tolerate high PER, video has strict delay requirements (5 frames per second).
- Voice cannot tolerate more than 400ms delay. Echo cancellation needed for much less than this, but over 400ms, there is a noticeable delay in conversation.

- PER up to 30% allowed for voice? This is in contradiction to our assumption of 1-2%. Any inputs/clarification on this (type of voice, quality vs. PER) would be greatly appreciated!
- We need the performance figures for other applications as well, but voice is probably most important.
- The idea of avoiding channels adjacent to those that are interfered, was brought up. Such channels are likely to also have problems due to high correlation in terms of multipath propagation and likelihood of these suffering ACI effects. Such strategy can speed channel assessment/replacement.
- As such frequency blocks/segments are widened, "scanning" of the band is faster, but accuracy/reliability of decision is compromised. Application may decide on optimal frequency-segment width. In this approach, there is no need for a wider BW in the receiver. The decision concerning a frequency segment is based on reception of a single channel through a filter corresponding to its narrow bandwidth.
- Statistic confidence calculations (channel assessment based on packet failures in each frequency) – KC from IPC said that the estimation is more problematic than originally believed. Calculations discussed last time are being delayed.
- Hongbing had raised the issue of when the assessment should be done - before/during connection?
- Nada, Anuj, myself and probably everybody agreed that the assessment should be done as much as possible (before, when possible, as well as during a connection).
- Assessing the spectrum status before a connection can be done by scanning the RSSI reading for the various channels, in the absence of transmission. This will not help for interferers that come up only after the connection has been established.
- Bijan suggested that idle devices "listen" to other Bluetooth piconets, find master's clock and address, so as to avoid collisions as much as possible by prediction where the interfering hops will be. The energy consumption of this must be considered as well as other practical aspects.
- For a stationary access point, as an example (not battery operated), there is no energy consumption issue, and such ideas can be more easily implemented.
- Anuj pointed out that such masters are typically busier and might not be available to perform such task all the time.
- Vitally mentioned that RSSI is mandatory in Bluetooth Class 1 devices due to the need to implement power control. I stated that my opinion is that this should become mandatory for all classes, and that most, if not all, vendors have RSSI in their receivers anyway.

Oren Eliezer
Texas Instruments

Teleconference #3

Summary of third IEEE802.15.2 AFH Teleconference (April 11-12, 2001)

Oren Eliezer, Texas Instruments Israel (Short Distance Wireless) - April 13, 2001

Attended:

TI Dallas (Anuj), NIST (Nada), TI Israel (Oren), IPC Taiwan (K.C. and H.K.), and Bandspeed Australia (Bijan, Hongbing, Vitally). Nada arranged for the bridge and lead the discussion.

Points/Goals for Discussion

Hopping sequence properties and the mapping from the original sequence were to be the primary focus of this third telecon. The latter was not accomplished.

Discussion of Hopping Sequence Properties

Points brought up / agreed upon:

- The period (cycle) of the hopping was discussed (advantages of short and fixed cycle for avoidance of similar type of system).
- Vitally brought up HomeRF FHSS as comparison. I clarified that in "fixed" I mean a fixed length for the hopping sequence, but not fixed contents.
- The number of frequencies should be prime so that all frequencies are used before a frequency is repeated when an application transmits only every N slots (e.g. N=3 for voice).
- The issues of supporting a scatternet and broadcast while implementing AFH were brought up.
- Vitally had pointed out that randomness helps decorrelate. I made the claim that a more "random" sequence does not help in terms of user-perceived performance when AFH is employed. The repetitive packet failures that would be experienced if two coexisting hoppers were to share a certain channel at the same time, would only help replace that channel faster, before this would even be noticed by the user.
- KC stressed that we need to consider the fact that a user may be moving around with a device, and the situation therefore cannot be considered stationary.
- I claimed that the actual pace of movement would be limited (3 meter/sec would be considered fast), so if the response time of the mechanism were such that negligible distances are covered within that time, then the system may be considered to be observing stationary propagation conditions.
- Testing through simulations is needed in order to validate a specific mechanism or a choice of parameters.

Oren Eliezer
Texas Instruments

Teleconference #4

Summary of forth IEEE802.15.2 AFH Teleconference (April 5, 2001)

Bijan Treister, Hong Bing Gan, Bandspeed Inc, Melbourne Australia - May 4th, 2001

Attended:

TI Dallas (Anuj), NIST (Nada), TI Israel (Oren), IPC Taiwan (K.C.), Chinn (Intel) and Bandspeed Australia (Bijan, Hongbing, Vitally). Nada arranged for the bridge and lead the discussion.

Points/Goals for Discussion

Mechanism of adaptive hopping was to be the primary focus of this forth telecon. The document "Proposed topics of IEEE 802.15.2 AFH ad hoc teleconference to be held on 3rd, May, 2001" was used as a reference document for the teleconference call.

Mechanism of AFH

Points brought up / agreed upon:

- Discussion started with the first criterion of backward compatibility and the fact that the issue of backward compatibility was an important issue for both the integration of our proposal with the existing standard.
- Bijan brought forward the idea that broadcast packets are one of the points which makes AFH difficult to implement because of the fact that a broadcast packet must address ALL slaves, and not just our "enhanced" device.
- Bijan suggested bad channel replacement algorithm using legacy Bluetooth hopping sequence does allow for some system of broadcasts to be enabled.
- Anuj queried if there were any time-critical broadcast packets, and exactly what the system is for broadcast packet.
- Intel man suggested that there is no well-defined explanation in the BT specs about the use of a broadcast packet in connection state.
- Hong Bing mentioned that Broadcast packets need to be retransmitted N times.
- Anuj queried about the probability that a system (any for that matter) would be able to guarantee a string of 'good' channels to allow these N transmission. Obviously, since Bluetooth hops 'randomly' we cannot guarantee this, however it is possible to suggest a method of sending the broadcast packets whenever all slaves are listening. (trade off);
- Intel man suggested that this N transmissions was a parameter negotiated, or embedded in the LMP layer and was application dependent (only MASTER sends broadcast packets).
- Oren suggested that the we should look into a mechanism which supports the possibility of multiple devices having different interference patterns at their end and creating a method by which a system could use different hopping patterns for each slave.

- I suggested that the interference sources should be generalised to common source, that is, all devices suffer the same interference – this may be sub-optimal but would increase classification time.
- Intel man said that individual classification for all devices would create degradation in bandwidth since "channel at a time" replacement, or replacement for each slave requires a large amount of traffic for negotiation of hopping sequences.
- Nada suggested that this is an optimisation problem and can be left for later, the most important problem to address is the actual sequence.
- Oren suggested that applications to target are possibly more important independent AFH sequences may be required.
- The notion of different AFH sequences is tabled and it will become a discussion point later
- Question as to which states to support. Oren suggested that the SNIFF State had some problems with devices that transmit in the same frequency twice in a row. Some clarification of this will be required so we can all understand the problem. This and other problems must be addressed so we have a good idea of what is required to be 'backwards compatible'.
- Oren suggests that a mechanism that is optimal for AFH may be sub-optimal in terms of the backward compatibility issue. (Anuj agrees)
- General consensus that Backwards compatibility is an absolute MUST for adoption by Bluetooth SIG and for marketability.
- Oren suggests that his system (in terms of backwards compatibility) is not feasible.
- Anuj suggests similar concern for good/bad channel blocking and suggests that Bandspeed and IPC's proposals may adhere. (needs to be looked at).
- Oren suggests that we require a mechanism to bring Bluetooth SIG into our discussions. They would benefit from out knowledge and discussions. (vice versa too)

Issues of next AFH telecon call

- Backwards compatibility matrix with states and problems that we might encounter, such as SNIFF and successive transmissions in same channel. Also Broadcast packet in Connection State.
- People who will attend IEEE interim: Anuj, Jay, KC, Bandspeed (?). Oren will not be attending this meeting.

Bijan Treister
Hong Bing Gan
Bandspeed, Australia

Teleconference #5

Adaptive Frequency hopping Ad-hoc group
9th May 2001

Attendees:

Nada (US), Hong Kun (IPC), KC (IPC), Oren (TI), Anuj (TI), Bijan (Bandspeed), Hong Bing (Bandspeed)

Points/Goals of discussion:

Backward Compatibility: *We will focus our discussion this time on how each of the mechanisms proposed to TG2 addresses backward compatibility. The goal is to study how a device implementing a new adaptive frequency hopping sequence can interoperate with other devices that use the original Bluetooth sequence while in different operating modes (such as Connection, Sniff, Page, Inquiry, etc...)*

Discussion minutes: (further details should be requested from ad-hoc groupers)

- Oren sent checklist information about AFH conflicts with different modes
- Oren suggested that master slave switch will be difficult with adaptive hopping.
- Suggestion that we should use the AFH only in connection state, cannot assume with 100% probability that all will receive.
- Likelihood of broadcast packets going through with re-mapping proposal is higher but not 100% sure.
- Connection state is one state, which should be supported. This should be the only one that we support. Bijan, Hong Bing and Anuj agree.
- Oren suggests that Broadcast packets are more application dependent.
- Reiterate that replacing one channel at a time creates more traffic, suggesting that there are not that many replacements. Oren suggests that we can reduce the number of packets required for one at a time replacement, thus reducing the problem.
- Open hearing at the FCC rules about the change on Thursday. Currently 0dBm we are allowed to reduce the number of hopping frequencies, but higher power devices produce restrictions in number of channels allowed.
- Backwards compatibility only needs to be addressed in connection state. Infact suggestion that AFH should only be considered in connection state.
- Oren suggests using a fixed cycle of 79 hopping frequencies or reduced sequence with grouping involved.
- Bijan questions problem with slaves reply with unknown sized packet.
- Anuj suggests that Lucent only allows 802.11 channels 1,4,7 and 10. This suggests that there are non-standard usages of channels for 802.11 systems. Suggests that most of the interference will happen on 1,6 and 11.
- Broadcast packets not possible without using replacement. May not allow for the Bluetooth™ qualification process.

- Suggestion that Park mode is a sub-state of connection state, and requires broadcast packets to be used.
- Bijan asked about SCO and ACL transmissions in grouping. There is a compromise. One can only be supported at a time.
- Pairing won't work with HV1 packets, works with a maximum 1 HV2 and 2 HV3.
- Suggestion that grouping is difficult using more than a point-to-point link. Anuj suggests that reserving the SCO traffic can be done, then the grouping around those reserved. Clarification on law of FCC as to whether this is legal.
- Anuj suggests that grouping proposal can be scaled for FCC law changes.
- Nada says that it may be allowed to not transmit in a bad channel. This is awaiting written approval from FCC
- Reduction in hopset will create less interference, and the FCC does not allow this. There could be a threshold in the number of bad channels to use. Oren suggests that FCC rules are not so well defined. Discussion of FCC requirements continues.
- Two concepts are left. Pairing and replacement. Need to find a way of deciding how to combine or use one of them.
- KC suggests that there should be flexibility for future systems.
- Nada suggests that a shorter cycle if it can be used would be a good thing.
- Nada asks who will attend the IEEE meeting; IPC, TI (Dallas) and Bandspeed will be attending.
- Various issues still remain to be resolved about the hopping replacement/mapping. We have these two methods and some method of integrating the two systems, or how/when they can both be used. Conditions that both systems can be used.
- Question as to when should grouping be used, when should replacement be used. What are the conditions?
- A document can be put together that is a summary of the proceedings of the AFH ad-hoc group.
- An accomplishment, summary, issues to be resolved.
- Summary of discussions, points of consensus, points of disagreement. Notes on ad-hoc group discussions. Attempt to have something out before Friday.

Concluded at Midnight, Melbourne Australia Time (+10GMT).